I. INTRODUCTION

A. General

STAT [redacted] proposes to execute a small study program directed toward significant improvement in the marking system used in the [redacted] Model E-80 High Speed Precision Coordinatograph. STAT Early operating experience with the present pen and ink system has indicated the desirability for a somewhat different design compromise and combination of features than the present system provides. Accordingly the program here proposed included a more detailed study of other types of marking systems and further evaluation in the light of present experience.

Following this initial introductory section, this proposal is divided into three more sections as described in the following paragraphs.

B. Requirements

Section II of this proposal discusses the requirements for a marking system as they were understood during the development of the system and as they are presently understood. While most of the original requirements remain, an improved capability for small symbols, faster "drying" and less tendency to spill and spatter have turned out to be more important characteristics than the ability to make lines that are entirely independent of writing speed. In addition to discussing these prime requirements, Section II reiterates the other basic requirements for a successful marking system.

C. Present Alternatives

Section III of this proposal discusses the present state of the marking system as a background for the proposed study. While many of the marking systems mentioned are obviously not applicable to the present system, it is useful to review them in order to note their various features and to insure that no desirable system is overlooked. Available marking systems include types which mark the paper mechanically, types which use liquid ink, and other types, largely these which use some form of radiation or conducted heat to mark the paper.

See proprietary statement on title page.

D. Proposed Study Program

Section IV of this proposal presents the plan of the study program which we believe will most economically result in an improved marking system. It is shown that the most difficult part of such a program is deciding in advance where the study should end since it is obvious from the beginning that at any point in the study more study will bring better results. We propose, however, a limited study including the testing of only a few actual breadboard types of marking system. It is expected that the system selected on the basis of these tests show sufficient improvement over the present system to be entirely satisfactory.

E. Price and Delivery

Section V presents our price proposal for the program outlined in the earlier sections of the proposal.

II. REQUIREMENTS

A. General

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In the development of the Model E-80 high-speed coordinatograph primary emphasis was placed upon the design and construction of the overall instrument and its control system. While it was recognized that the marking system was a potential source of operating difficulty, two important factors prevented any extensive development of a marking device. First, difficulties in other areas of the system delayed construction to the extent that no time was available for such development. Second, since the success of a marking system is intimately dependent upon the actual types of operation of the equipment, no effective experimental work could be done prior to the accumulation of some operating experience. The pen system was accordingly designed on the basis of the best information available. It has subsequently become evident that this particular application requires a somewhat different approach, as yet not clearly defined.

In order to assist in arriving at a clearer definition of the total marking system requirement, this section of the proposal discusses briefly the background of the present pen, and then the overall marking system requirements as they are now understood.

See proprietary statement on title page.

B. Background

The basic requirements for the E-80 pen system were a combined dotting and line-drawing capability, the generation of diazo-reproducible copy from a roll supply of blank material, and the ability to operate for significant periods of time reliably without any manual attention or intervention.

In meeting these basic requirements there were other characteristics which had to be given consideration in the final system choice. For economy, procurement convenience, and ease of handling it was desirable to use standard drafting paper as the blank material. For speed in operation, it was desirable to use a single marking device for both dotting and line work. It was clearly desirable to use a system which did not require any development, stabilization, or fixation after a plot was made. Finally, it was clear that some quality criteria would be important in assessing the final success of the system, though no definite statement of such criteria was formulated.

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Marking systems useable on ordinary tracing paper which we have either tested or used in [redacted] equipment include graphite pencils, ball-point pens, ribbon-percussion devices, and capillary ink pens. Each of these presents problems of some magnitude for an application such as the E-80 system. Pencils provide highly reliable operation, but at the expense of essentially uncontrolled line width and density. Ball-point pens present an apparently unavoidable tendency to skip, they do not print successive dots, and they have relatively unreliable starting characteristics. Ribbon percussion devices are excellent for dotting and point-printing but essentially unuseable for line work. Capillary-ink pens provide good density and line width control, excellent starting characteristics, and good line performance only at the expense of slow drying and the ever-present probability of spills, runs, and smears. Of these systems, the capillary-ink pens provide the greatest flexibility in terms of the widest selection of inks, pens, paper, etc. to meet the specific needs of any application.

For the E-80 coordinatograph, it was decided to install a capillary-ink system. Two types of pen were studied and tested; one was a standard drafting pen of the Rapidograph type, the other was the special-purpose EAI plotter pen. The latter was selected principally

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See proprietary statement on title page.

because it is much better suited to the extremely rapid up and down action required in this application. Half a dozen types of ink were tested for tendency to clog the pen, low enough viscosity to make essentially equal density lines at all writing speeds, dotting capability, etc. The suggested ink was the one which provided the best all-round capability in our tests. Its low viscosity resulted in some tendency to drip, its unusually low surface tension caused it to spread rapidly if the pen tip was in contact with a free drop, and its slow drying characteristic was undesirable. Other inks which avoided some of these troubles, however, flowed too slowly to make good lines, dried so fast as to clog the pen overnight, or exhibited other equally serious faults. The extended-capacity reservoir, constant-head ink feed was therefore designed for the suggested low viscosity ink.

Subsequent experience with the system has shown that a very frequent mode of operation involves the generation of small symbols, figures, and similar marks in which the pen is making many short strokes, often crossing previous lines still very wet, or stopping on a wet spot. As a result, an undesirable amount of blotting, smearing, and dripping occurs. It is therefore necessary to re-evaluate various marking systems to see if a more optimum solution to the actual operating problem exists.

C. Present Requirements

Initial operating experience now allows us to re-examine marking system characteristics and to state operating requirements in more detail than was possible heretofore.

In the first place, the basic requirement for diazo-reproducible copy remains firm. Further, the copy material must be supplied from a roll and the system must operate reliably when unattended.

Work consists of dots, lines and symbols made up of a number of short lines which may cross and overlap.

While economy is still important, quality of work should take precedence over low cost of materials. Similarly, working speed should not be compromised to achieve low material cost.

See proprietary statement on title page.

Post-plot development, fixation, or stabilization remain undesirable. If the work is immediately visible on the plotter, however, an automatic dry-to-dry stabilization operation would be acceptable if such a process would yield superior quality work.

Adequate quality remains the most difficult characteristic to measure in any quantitative way or to evaluate in terms of its cost in other desirable features. Some qualitative statements may be made, however, about each class of work.

Dots are made by a momentary operation of the marking device at a time when the carriage is stationary. Each such operation must have a high probability (on the order of 0.99 or higher) of leaving an observable mark on the plot medium. Preferably the dots should be highly uniform in size, shape, and density.

Lines are made by operating the marking device with the carriage stationary and then keeping it in operation while the carriage moves to a new location and again stops. Lines should start clearly at the beginning point and run continuously to the ending point. Line width and density should be uniform and independent of the travel speed of the carriage. Lines should cross each other without spreading or skipping at the intersections. It should be possible to initiate or terminate a line on another without spreading or skipping.

Symbols combine the requirements for lines and dots since they consist of a number of brief operations of both marking device and carriage closely spaced in time and overlapping in geometry.

Beyond these specific requirements are a number of fairly obvious general requirements. Operating experience has shown that it is unrealistic to expect the vacuum system to eliminate all bulges from the paper. Hence the marking system must be capable both of drawing continuous lines across or along bulges and of not marking the paper when crossing bulges in the off condition. The system should avoid catastrophic conditions such as cutting through the paper. A less important desirable characteristic would be the capability of overrunning the edge of the paper accidentally and returning without damage to either paper or marking device. It should not be necessary to maintain an unusual environment

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in the plotter room, as high humidity or total darkness, for example. Materials and by-products may not be unpleasant or toxic to handle, nor may they be unusually inflammable or otherwise dangerous in use or in storage.

With these requirements in mind we can go on in the next section to examine some of the characteristics of available marking systems.

III. PRESENT ALTERNATIVES

A. General

Marking systems today are many and marvelous. Yet there is no obvious candidate which combines the characteristics which are required in the E-80 system. This section considers a number of the systems which offer some promise of being useful in the present equipment. Generally these systems fall into three broad categories; systems which employ some mechanical action to mark the medium, systems which deposit a liquid, and systems which use electric current, light, heat, or other form of energy to create a visible change in the medium. These three groups are discussed in the following paragraphs.

B. Mechanical Systems

Mechanical marking systems rely upon mechanical force or friction to transfer pigment from a source to the paper or to so modify the surface of the paper as to have a visible trace.

The simplest mechanical marking device is a wax or plastic pencil containing graphite or other pigment. Systems using pencils have good marking characteristics, write dry, hence never generate drips and smears, and work well with ordinary paper. Unfortunately they are fragile, hence subject to unpredictable catastrophic failure, and they do not generate lines and dots of uniform width and density.

A more complex mechanical system employs a hard stylus to effect a transfer or modification of pigment from an intermediate ribbon or sheet. The simplest case of this type system uses a full size sheet of carbon paper over the work. The writing stylus merely presses the carbon paper against the work wherever marks are desired. A similar

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See proprietary statement on title page.

effect is achieved with so-called carbonless carbon paper in which a coating on the work sheet changes color when a treated overlay sheet is pressed against it. In either case the work is not visible until the overlay sheet has been removed. A more complicated use of this principle uses a ribbon of overlay material carried by the marking device. While such a system is ideal for dotting, in order to be usable for lines a rather complicated rotating ribbon feed system must be provided. While such systems can mark ordinary paper, they use relatively large quantities of the intermediate material which may be expensive and is always inconvenient.

A third class of mechanical system relies upon the mechanical alteration of the surface of the work sheet to create a visible line. Many such systems employ a pigment which is trapped in minute opaque corpuscles in the coating of the sheet and released when the corpuscles are broken by mechanical pressure, or a continuous pigment which is normally covered by an opaque scattering layer of wax or other crystals and exposed when the mechanical pressure of the stylus removes or compresses the wax crystals. These systems suffer two serious disadvantages. First, the pigment is uniformly present over the entire sheet initially, hence the material is usually quite opaque to start with. Diazo reproduction tends to be less than satisfactory. Second, the materials are expensive.

Other forms of pressure-sensitive materials use a two reagent system in which one colorless reagent is released into the paper to activate the other and cause a color change as a result of the passage of a pressure stylus. These systems can provide good lines and dots relatively insensitive to tracing speed and they make good diazo copies. On the other hand, they remain sensitive to scratches, folds, etc. and hence deteriorate with usage.

C. Liquid-Ink Systems

The widest variety of marking devices rely upon the transport of a liquid ink from a reservoir to the paper to form the visible trace. The following paragraphs discuss some of these systems but cannot be considered an exhaustive survey.

The simplest liquid ink system is the capillary pen. This system employs a narrow tube to convey liquid ink from a reservoir to the paper. When the tube is in contact with the paper ink flows into or onto the paper but when the tube is lifted, surface tension

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See proprietary statement on title page.

at the tip prevents the ink from dripping. A very wide variety of paper-pen-ink systems are available, but all share certain common characteristics. Once the ink is on the paper it is necessary that it cease flowing and become "dry" as rapidly as possible. On the other hand, it should not become viscous or solid in the pen tip under indefinitely long exposure with the tip off the paper or stationary on the paper. Two methods of compromising these requirements are used with traditional volatile-solvent inks. One uses a low-volatility solvent such that the ink doesn't dry either in the pen tip or on the paper. This type of ink is formulated with a low surface tension and best used with absorptive paper. The ink then penetrates the paper rapidly and thereby resists smearing and offset even though not really dry. Because of their high wetting characteristic such inks tend to drip, splash, and spread. It is this approach which is presently used in the E-80 system. The other approach is to use a more volatile solvent so that the ink does truly dry on the paper and then to equip the pen with some device to resist clogging when the ink dries in the pen tip. Drafting pens of the Leroy and Rapidograph type use a fine wire insert within the tubular pen tip. When the pen is off the paper the wire protrudes slightly, then when the pen is lowered, the motion of the wire back up the pen tip opens an adequate ink passage. This type of system can work with inks of higher surface tension and therefore which tend less to drip and run. On the other hand, their anti-clogging characteristics are less than complete. When used with low-volatility inks these pens show no apparent advantage over simple tubular pen tips. A recent new form of capillary pen employs a pigmented wax for its ink. The ink reservoir and pen tip are heated electrically so that the wax is molten. Upon contacting the cooler paper it cools to a solid state rapidly and is thereafter constructively dry. We have not been able yet to determine the spill characteristics of this ink as yet. Whatever ink system is used in a capillary pen, the viscosity of the ink is another critical parameter. Overly viscous inks will tend to write narrower lines or skip at higher writing speeds while inks of too low a viscosity tend to run out along intersecting and connecting lines and drip and run back at the ends of lines.

Another class of liquid-ink pen employs an ink of very high viscosity and uses a mechanical system to apply the ink and impress it into surface interstices of the paper.

There are two types of such system in use. The commonest is the ball-point pen. In the ball-point pen a small hard ball is mounted so that one side is in the ink reservoir and the other is in the open and the ball can rotate in its mounting. The ink is a gelatinous mix of very low volatility and high viscosity and wetting ability. When the pen is moved over the paper, the surface of the rolling ball becomes coated with ink when in the reservoir and transfers the ink and presses it into the porous surface of the paper as it rolls over the paper. The ink appears "dry" immediately since its free surfaces lie generally below the surface of the paper fibers. Runs and drips are impossible since only motion of the ball surface can transfer ink out of the reservoir. On the other hand, since no ink is transferred without ball rotation, the system cannot deposit dots reliably. Similarly skips occur when the writing direction changes, as well as at other random intervals. The gelatinous nature of the ink seems to make ink supply to the ball somewhat unreliable, especially if reservoirs become larger.

The other type of pen system using high-viscosity ink is a recent development of the Brush Instruments Division of the Clevite Corporation. In this system a conventional tubular pen similar to a capillary pen is supplied with high viscosity, low volatility ink under pressure from a simple pump at the reservoir. The pen tip is carefully lapped to the surface of a relatively heavily coated paper and tip pressure is adjusted high enough so that an effective seal is formed between the pen tip and the paper. As the pen moves, the hydrostatic pressure of the ink forces it into the surface irregularities of the paper where it remains as a visible line after the pen has passed. Again, while the ink remains fluid it appears "dry" since its liquid surfaces are protected by the higher surfaces of the paper fibers and coating particles. If the pen is lifted, it is necessary to remove the pressure or the ink flows freely from the pen tip. The practicality of this system for the E-80 application depends heavily upon whether a satisfactory means for controlling ink pressure in synchronism with pen up and down motions can be devised.

D. Other Systems

In addition to the above marking systems which basically depend upon the mechanical transfer of a pigment or activator from a reservoir to the working medium there is a variety of marking systems in which the color of a component of the working medium is

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changed by the action of electrical current, heat, radiant energy or the like.

The most familiar of these are, of course, photographic emulsions. The conventional silver halide emulsion has the capability of producing extremely high quality copy but the serious disadvantages of requiring chemical development, a dark operating environment, and of providing no immediately visible record of action.

There are so-called "printing-out" papers using silver halide emulsions which provide immediately visible images of lines drawn with very intense light. These systems forego a power-amplification factor of 10^6 or more provided by the chemical development of more conventional materials. It is common practice to make up some of the loss by means of an over-all "flash" exposure of the material. Unfortunately, all exposure to actinic ambient light during the writing of a plot forms a part of the flash exposure, hence control is difficult unless the plot is made in semi-darkness or under light of limited spectral energy distribution. The records so formed are transient unless a stabilization or fixation step is applied to the finished plot.

Other photographic systems suffer approximately the same 10^6 loss of sensitivity compared to conventional silver-halide systems and are not so readily sensitized by "flash" exposure. Most also require some development processing. A potentially more interesting class of radiation-sensitive materials are the thermographic papers. These change color when heated, hence can be used with an intense beam of infra-red illumination. Thermographic materials may be essentially insensitive to visible light, or in some cases may be deactivated slowly by visible light and more rapidly by ultra-violet. With such materials fixation occurs spontaneously in a lighted environment or with the first pass through a diazo machine. Thermographic materials are very sensitive to writing speed, the line becoming narrower at high speed and spreading at low speed. It is therefore necessary to modulate the exposure lamp to offset this effect, and even so very fine lines would be difficult to obtain.

Thermographic materials may also be used with a hot stylus, though there appears to be no important advantage of a stylus over a sufficiently energetic infra-red light beam.

See proprietary statement on title page.

Another class of material can be exposed by light and fixed by heat. Typical is a transparent film material tradenamed Kalvar. While the material produces excellent and permanent copy, the copy is not visible until after the thermal development.

Another particular form of thermal recording uses an electric spark to mark the paper. Produced under the trade name Teledeltos, this material is widely used in facsimile recording. It shares with the light-sensitive materials the advantage that marking can be controlled electrically without any mechanical raising and lowering of pens or styli. It suffers the disadvantage that recording is accompanied by a small amount of smoke and a variable amount of radio frequency interference.

Closely related is an electrically sensitive material tradenamed Alfax also used in facsimile recording. This paper turns brown when a low-voltage current is passed through it from a steel stylus. Unfortunately the paper must be damp enough to carry electrical current in order to be marked. This latter requirement limits the use of Alfax to systems which can be operated in an atmosphere with very high humidity.

IV. PROPOSED STUDY PROGRAM

A. General

In setting up a program to investigate a subject as rich in variety of approach and engineering choice as that of marking paper, the prime problem is to establish some means of limiting the study. It seems clear that at any point in such a study, the results to date will be susceptible to improvement upon more study. For practical reasons, however, it is necessary to place limits on the time and money cost of a study, hence the technical goal must be limited to such general terms as "significant improvement" over the present system. The following paragraphs describe a proposed program which we believe will lead to a significant improvement in marking system most economically.

B. Outline of Program

The first step in the proposed program is to round out the summary of marking system types discussed in Section III of this proposal with detailed library information,

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manufacturer's literature and samples of work. In the course of this study, it is expected that other types and variations will also be uncovered.

The second step is to review the data and select a limited number, preferably less than four or five, of systems which show the best prospects of being effective in the E-80 system. Samples of the selected systems will be purchased.

The third step is to build test fixtures to permit tests of line quality vs. writing speed, dotting capability, total line capacity on one filling, diazo reproducibility, etc. under controlled conditions.

The fourth step is to evaluate the results of the tests, to select the most promising system, and prepare a report.

C. Probable Results

It is expected that a program such as that outlined above will lead to the recommendation that the present marking system be replaced with a different system; or at least a different ink. The study will also produce a good evaluation of the quality to be expected in the copy, and data on the cost of operating, materials and supplies as well as a firm price for the system design and development so that a meaningful economic evaluation can be made. In the unlikely and unexpected event that only negative results are available from the test work, a recommendation will be made for the direction which should be taken in future studies.

D. Estimated Cost

It is estimated that the program outlined above will require approximately two man-months senior engineering staff effort and approximately one man-month each of drafting, project technician and machinist effort and will require about [redacted] STAT purchased materials. We are happy to quote a fixed price of [redacted] for this program STAT or we will undertake the program on the basis of time-and-material not to exceed STAT [redacted] at the following rates:

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It is estimated that the program can be completed in approximately three months.

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